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Effects of Organic Load on Basic Geotechnical Properties of Compacted Sand-kaolinite Mixture

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ABSTRAK

Empat teras PVC bergarispusat 15 cm telah dipadatkan sedalam150 cm dengan campuran pasir dan kaolinit. Larutan Naterium asetat yang memberikan kandungan BOD (permintaan oksigen biokimia) setinggi 20,000 ppm (mg/L), 30,000 ppm, 40,000 ppm dan 50,000 ppm telah disuapkan ke atas turus. Analisis ciri fizis dan kimia tanah seperti had Atterberg, graviti spesifik, pH dan kandungan organik, telah dilakukan. Ciri ini telah didapati agak berubah selepas suapan selanjar selama 40 hari; telah didapati bahawa kandungan BOD lebih tinggi telah meningkatkan kandungan organik dan pH tanah dan dengan ini graviti spesifik dan had Atterberg teh terturun.

ABSTRACT

In the laboratory, four PVC sand-kaolinite mixture columns, each of 150 cm depth and 15 cm diameter, were fed with solutions of sodium acetate equivalent to 20,000 p.p.m., 30,000 p.p.m., 40,000 p.p.m., and 50,000 p.p.m. BOD (biochemical oxygen demand). Soil physical and chemical properties, such as Atterberg limits, specific gravity, soil pH and soil organic content, altered markedly within 40 days of continuous feeding. The results showed that feed with higher BOD values increased the soil organic content as well as soil pH; and thereby the specific gravity and Atterberg limits were lowered.

Keywords: geotechnical properties, organic load, sand-kaolinite, effluent disposal, kaolinite, soil properties, soil pH, soil organics

INTRODUCTION

Malaysia is the world's largest producer of palm oil (Abdul Hai 1987). The amount of effluent produced from palm oil mills was 12 million tons in 1983, which is equivalent to 660 tons of BOD per day or 240,000 tons of BOD per year. This is equivalent to the BOD generated by 14.6 million people (Abdul Hai 1987). Raw palm oil mill effluent contains BOD ranging from 10,250 p.p.m. to 47,500 p.p.m., due to carbohydrate, sugar, polysaccharide, acetone, acetate etc., and a very low amount of sodium with the Na:Ca ratio of 43:315 (Chan *et al.* 1980; Anon. 1982; Mohd. Ali 1986; Abdul Hai, 1987).

Atterberg limits are correlated to various geotechnical properties such as shear strength, permeability, compressibility, swelling etc. (Wasti 1987). A

notable decrease in liquid limit was observed upon drying of marine clay samples from the south-west coast of India (Rao *et al.* 1989). The decrease in Atterberg limits is due to the presence of organic matter, hydrated sesquioxide and halloysite mineral (Townsend 1985). Sridharan *et al.* (1988) tried to elucidate the controlling mechanism of liquid limit of natural soils, and declared a correlation exists between liquid limit and clay size based on ion exchange phenomena. Sivapullaiah and Sridharan (1985) observed the effect of polluted water on the physico-chemical properties of clayey soils. Significant reduction in specific gravity due to phosphate adsorption was found. For sodium and calcium saturated kaolinite, the liquid limits are 52% and 73% respectively (White 1949). Schofield and Samson (1954) observed that edge face flocculation is also influenced by soil pH. This is because particles develop a positive charge on the acceptance of hydrogen ions by the edge hydroxyl group from the surrounding medium. With more acidic soils, there is greater capability of hydrogen ion interaction with edge hydroxyl group and therefore, higher edge positive charge and degree of positive edge-negative face flocculation. Liquid limits were plotted as a function of exchangeable sodium content of kaolinite soil (Sridharan *et al.* 1988), and it was seen that the wide scatter between these parameters suggests that diffuse double layer of sodium ion cannot contribute to the liquid limit of kaolinite soil. A similar conclusion had been drawn by Sridharan and Venkatappa (1975) of kaolinite soil.

This paper presents results from a study carried out to investigate the change of soil basic properties, i.e. specific gravity and Atterberg limits, due to disposal of organic waste on soil.

MATERIALS AND METHODS

The soil column apparatus consisted of four PVC columns. Each column was of 15 cm diameter and 150 cm height. The columns were divided equally into 5 sections. An extra 30 cm of identical PVC was set up on top of the soil column for maintaining uniform flow. Layout of this PVC soil column is shown in *Fig. 1.*

Soil mixtures were of 25% mining sand of 1.18 mm sieve down grade and 75% white kaolinite. Kaolinite is the extreme clay structure of two sheet minerals with a non-expanding lattice and low cation exchange capacity. Commercial kaolinite was used for this experiment. Initial properties of this mixture were specific gravity - 2.65, liquid limit - 58.00%, plastic limit - 35.00%, linear shrinkage - 8.57%, soil pH - 3.83 and soil organic content -0.06%. Initial properties of sand were: specific gravity (after oven drying at 105°C) - 2.63, pH - 5.89. For kaolinite, the initial properties were specific gravity (after oven drying at 105°C - 2.71, pH - 3.67, liquid limit - 77.50%, plastic limit - 36.63% and linear shrinkage -9.29%. Soil was then moistened for 2 days with 32% by weight distilled water at pH 6.62.

Hand compaction was done in every section according to the standard Proctor method to maintain bulk density at around 1.95 gm/cc. The pieces were

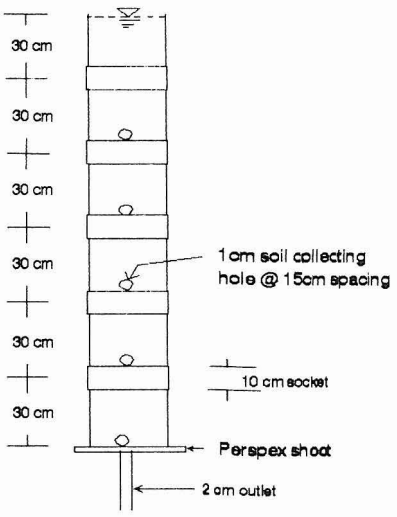

Fig. 1. Layout of PVC soil column

connected tightly by 10 cm PVC sockets and all joints were closed with silicon glue. At lower layers of each section, especially above the socket, three 1-cm soil collecting holes were made at equal intervals. Soil was homogeneously mixed in the dry stage of 25% mining sand and 75% kaolinite by weight basis. At the bottom of each column, a 25 cm x 25 cm perspex sheet 15 mm thick with a 2 cm central hole was joined to a 6 cm long rubber tube (2 cm diameter) enclosing filter paper to act as an outlet. Sampling holes were closed by tape, except during sampling time, to maintain the downward wastewater flow. All columns were placed on a frame to prevent disturbance.

BOD Preparation and Test Procedure

Sodium acetate was used as a source of BOD. The BOD was calculated as below:

$$4COOCH_3 + 7O_2 \rightarrow 8CO_2 + 6H_2O \quad (1)$$

From the left side of the above equation,

224 mg oxygen = 236 mg acetate

1 mg oxygen = 236/224 mg acetate

So, 20,000 mg oxygen = (236/224) x 20,000 = 21,071.42 mg/litre acetate. The molecular weight of NaCOOCH3.3H2O is 136, and 59 mg acetate is contained in 136 mg of sodium acetate. Therefore, 21,071.42 mg acetate is satisfied in 48,571.40 mg sodium acetate. For feed, 48.5714 gm sodium acetate was mixed

with distilled water to make one litre of solution to obtain 20,000 p.p.m. BOD value. Maximum BOD value in raw palm oil mill effluent was found to be 47,500 p.p.m. (Anon 1982). Concentrations of 20,000 p.p.m., 30,000 p.p.m., 40,000 p.p.m. and 50,000 p.p.m. BOD solution were used in four PVC columns according to the above procedure. Samples were collected with a small stainless steel spoon and kept on glass plates 15 cm x 15 cm size to avoid chemical reaction during drying. About 200 gm dried samples were collected at the treatment age of 40 days for soil Atterberg limits, soil specific gravity, soil pH and soil organic content determination.

Analysis of Soil Organic Matter

Hach DR 2000 spectrophotometer was used to perform the soil organic matter test (HACH method no. 8097). Into each 250-ml conical flask was placed 1 gm sample (air dried for 5 days at 29-33°C) and 10 ml 1N $K_2Cr_3O_7$ solution followed by 20 ml concentrated sulphuric acid. Each flask was slowly shaken for 10 minutes reaction time. Addition of sulphuric acid to each sample flask was made every 30 seconds. After 10 minutes reaction of the first sample flask, 100 ml of deionized water was added to each flask, also at 30-second intervals. A standard solution was prepared without a soil sample. All prepared samples were then transferred into 50-ml glass cylinders to stand overnight for the soil to settle out. Two or three tests were made on each sample to obtain a mean value with about 5% difference. Spectrophotometer accuracy was standardized by using potassium hydrogen phthalate (KHP) solution. The test was also verified by using the British Standard method (BS 1377, 1975, 3, test no. 8).

Analysis of Soil pH

Soil pH was tested in 1N KCl solution with a soil-water ratio of 1:2.5 (Sharifuddin and Dynoodt 1981; Abdul Hai 1987). Two 4-g specimens (air dried for 5 days at 29-33°C were kept in 50-ml glass beakers with 10 ml of 1N KCL solution to obtain an average reading within 2% limit. After shaking, stable soil pH value was read from a calibrated digital pH meter (HANNA model no. 8520).

Analysis of Soil Specific Gravity

Soil specific gravity was determined by using the British Standard method (BS 1377, part 2, 1990, section 8.3) using an average of two specimens within 2% difference.

Analysis of Soil Liquid Limit

Liquid limit tests were conducted according to the British Standard method (BS 1377, part 2, 1990, section 4). Average penetration values of two penetrations were accepted to within 0.5 mm penetration difference.

Analysis of Soil Linear Shrinkage Limit

Soil linear shrinkage limit tests were done using the British Standard method (BS 1377, part 2, 1990, section 6.5). There was no weight loss of sodium acetate in oven drying at 110°C for 24 hours.

RESULTS AND DISCUSSION

Fig. 2 shows the liquid limits as a function of BOD. At any depth, the liquid limits are different due to various amounts of BOD applied. This figure also shows that the surface soil, with sodium acetate in feed samples, had a higher reduced form of liquid limits than the soil at lower depths. *Fig. 3* gives the liquid limits in terms of soil organic content and shows decreasing liquid limits with increasing soil organic and BOD content. The best fit equation for *Fig. 3* with both linear scaling is

$$Y = 65.26 - 29.18X \quad (2)$$

where Y is liquid limits (%) and X is organic content (%). This shows the effect of increasing organic content on the liquid limits of this soil.

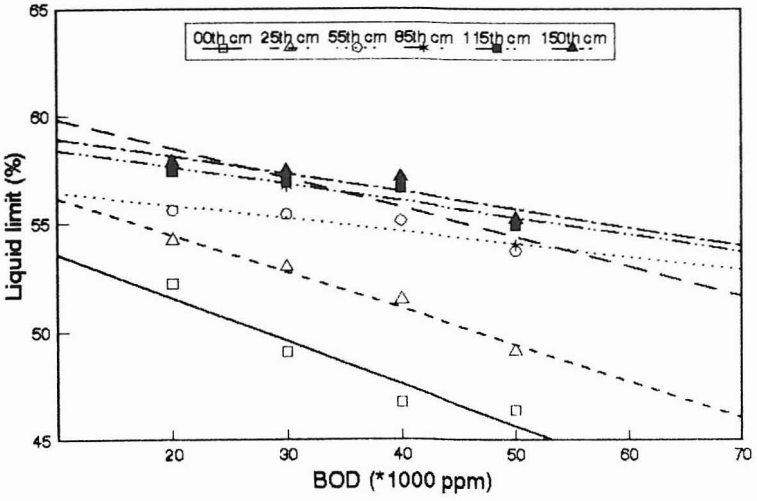

Fig. 2. Liquid limit as a function of BOD

Fig. 4 shows the changing of liquid limits with soil pH. Increasing the soil pH decreases liquid limits. This is because a low pH develops a positive edge to negative surface interaction, leading to flocculation from suspension. However, stable suspensions or dispersions of clay particles are formed at high soil pH. The best fit linear relation with an r-squared value of 0.83 is

$$Y = 64.55 - 1.95X \quad (3)$$

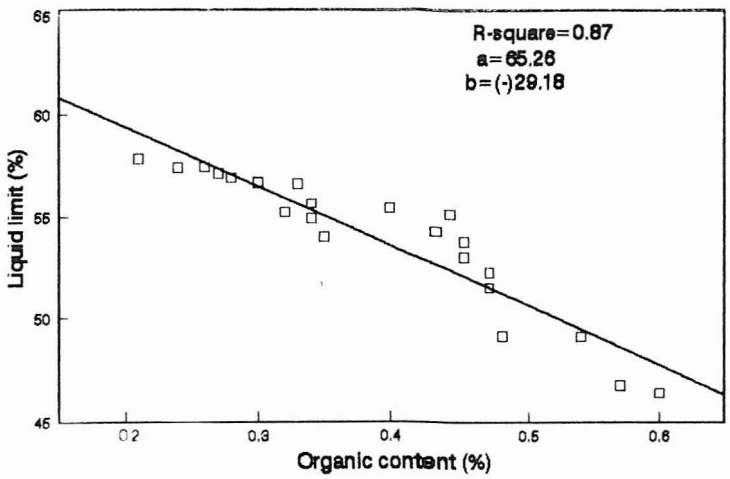

Fig. 3. Liquid limit as function of organic content

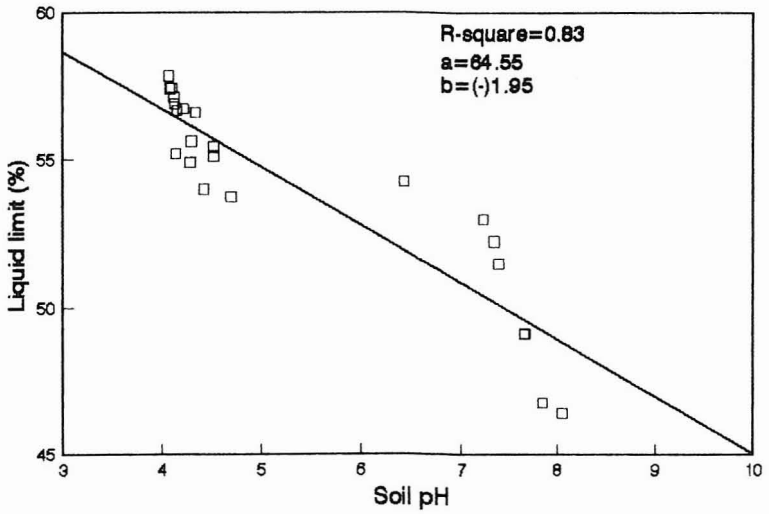

Fig. 4. Liquid limit in terms of soil pH

where Y is liquid limits (%) and X is soil pH.

A logarithmic regression was obtained, with log scale on the horizontal axis and linear scale on the vertical axis, with an r-squared value of 0.87, for the following equation.

$$Y = 0.66 + 26.31 \text{ LnX} \quad (4)$$

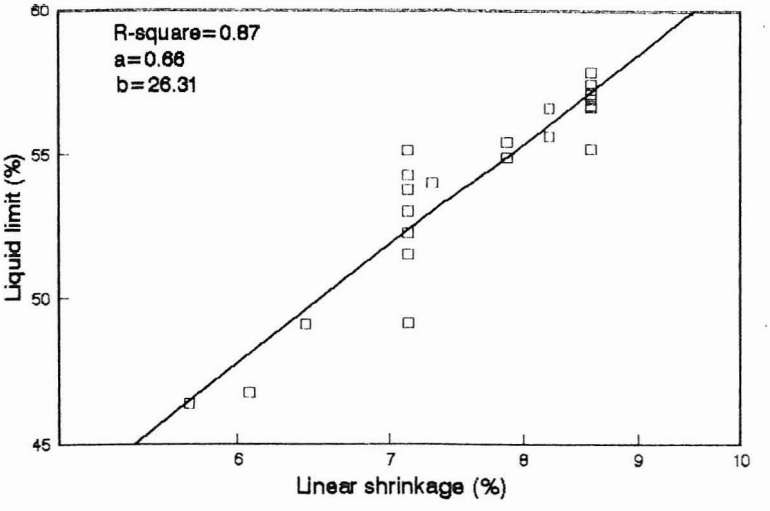

Fig. 5. Liquid limit in terms of linear shrinkage

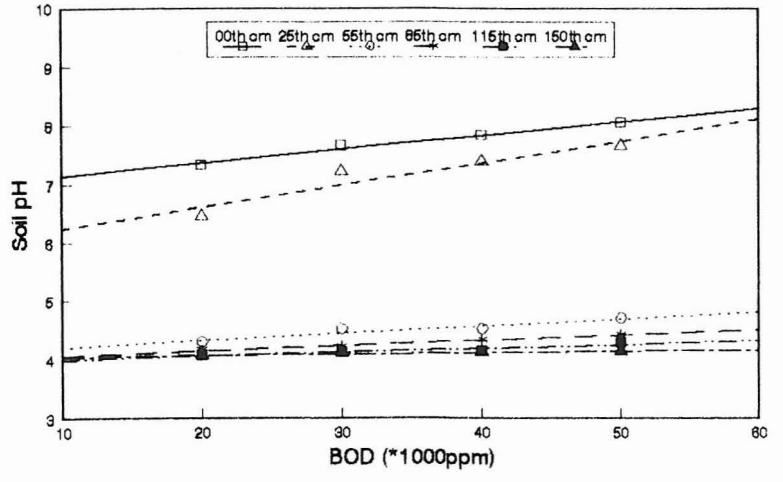

Fig. 6. Soil pH as a function of BOD

where Y is liquid limits (%) and X is linear shrinkage (%) (see *Fig. 5*). An increase in liquid limits was followed by an increase in shrinkage limit from surface soil to about 150 cm depth, except at 25 cm and 150 cm depths where the increments of linear shrinkage were the same in all columns. This increment indicates that the liquid limits of kaolinite are strongly controlled by clay structure. Clay structure is formed due to interparticle attraction and repulsion forces. *Fig. 5* exhibits the same behaviour (Sridharan *et al.* 1988). Increase in BOD values increased the soil pH, particularly in the upper soil layers *(Fig. 6)*.

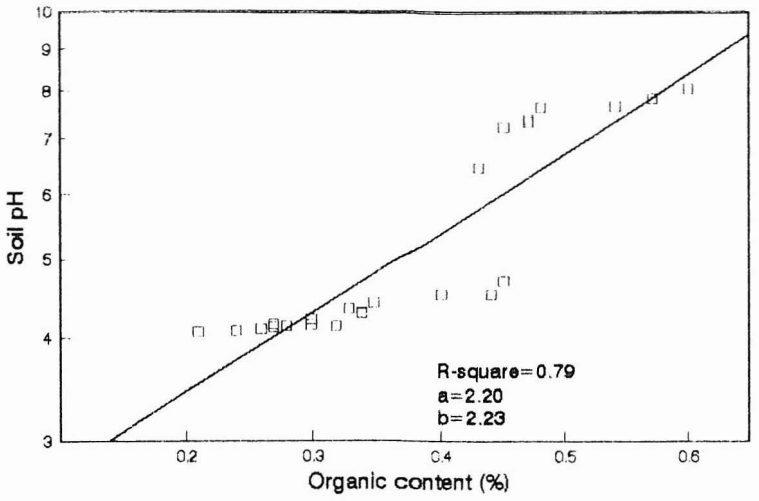

Fig. 7. Soil pH in terms of organic content

Fig. 7 shows the influence of soil organic content on soil pH. Correlation of soil pH and soil organic content according to depth is drawn in this figure, with logarithmic scale on the Y-axis and linear scale on the X-axis.

The correlation obtained is

$$Y = 2.20e_{2.23X} \qquad (5)$$

where Y is soil pH and X is soil organic content (%). Therefore, increase in BOD load would lead to decrease in liquid limits in sand-kaolinite mixture. According to Hamidon and Faisal (1989) liquid limits of kaolinite mixed with nitrobenzene, benzene, phenol, acetone and water are 105%, 80%, 70%, 55% and 60% respectively. Liquid limits of water-treated kaolinite are higher than acetone-treated kaoline. Hamidon and Faisal (1989) also observed increasing liquid limits with increase in dielectric constant of highly active minerals (i.e. activity of 4.5 and 2.8) such as bentonite, Na-montmorillonite and Ca-montmorillonite. Numerous positive charges at the broken edges of kaoline have major effects on the forces of interaction. The resulting repulsive forces generate a dispersed structure. The low dielectric constant of organic chemicals is responsible for reducing the double layer thickness (Fernandez and Quigley 1985). When the double layer shrinks, the soil particles tend to pull closer together, i.e. to flocculate and form aggregates. The results obtained by Sridharan *et al.* (1988) suggest that the interparticle attraction and repulsion forces determine the particle arrangement, which governs the liquid limits. At low soil pH and in the presence of divalent and trivalent cations there is built up positive edge-negative face

flocculation, while at high soil pH and in the presence of monovalent sodium ions, a barrier to particle flocculation is formed. Geometric arrangement of clay particles controls the liquid limits of kaolinite. Greater degree of particle flocculation will enclose higher void spaces for entrapment of water and thus increase the liquid limits. In other words, soils with a lower degree of particle flocculation possess lower void space and develop lower liquid limits. Dielectric constants at 20°C of water, nitrobenzene, methanol, acetone, phenol, benzene and haptene are 80.12, 35.74, 33.62, 20.70, 13.13, 2.28 and 1.92 respectively, and liquid limits of kaolinite mixed with them are 60%, 105%, 74%, 55%, 70%, 85% and 116% respectively (Foreman and Daniel 1986; Hamidon and Faisal 1989). Increasing dielectric constant means increasing the liquid limit in highly active (i.e. activity of 4.5 and 2.8) minerals (Hamidon and Faisal 1989). But a low active mineral like kaolinite (activity 0.32) does not follow this rule. However, decreasing soil liquid limits were observed with increasing BOD values in these experiments.

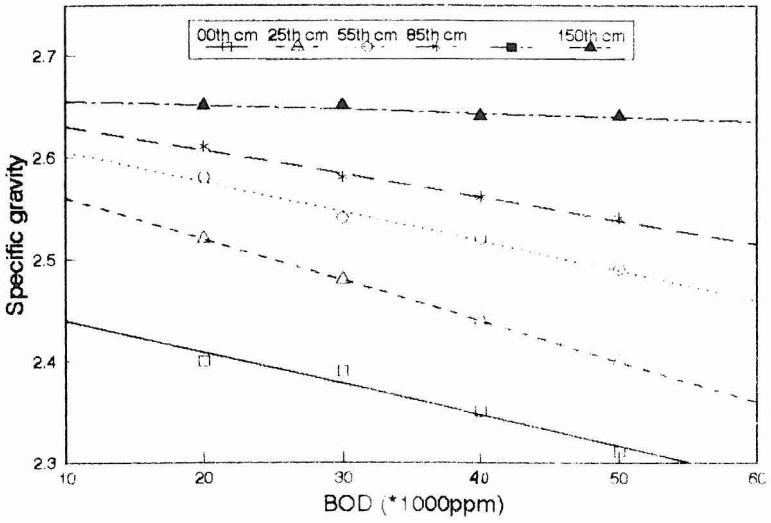

Fig. 8. Specific gravity in terms of BOD

Fig. 8 shows the variation of soil specific gravity with different amounts of BOD. Decrease in specific gravity was observed with increasing BOD. *Fig. 9* shows the variation of soil specific gravity with organic content due to different amounts of applied sodium acetate. At any soil depth, the greater amount of organic content the lower the value of specific gravity. The best fit linear correlation in *Fig. 9*, with r-squared of 0.93, is:

$$Y = 2.88 - 0.92X \qquad (6)$$

where Y is soil specific gravity and X is soil organic content (%). This equation shows decreasing specific gravity with increasing soil organic content. Franklin *et al.* (1973) showed that specific gravity is reduced by increasing organic content.

Sreepado (1982) studied the physicochemical properties of anion-adsorbed clays; anions such as phosphate and acetate adsorption changed the soil physico-chemical properties of both kaolinite and montmorillonite clay significantly. Initial specific gravity values of sodium kaolinite and calcium kaolinite were 2.71 and 2.66 respectively, but after treatment with phosphoric acid these values changed to 2.45 and 2.59 respectively.

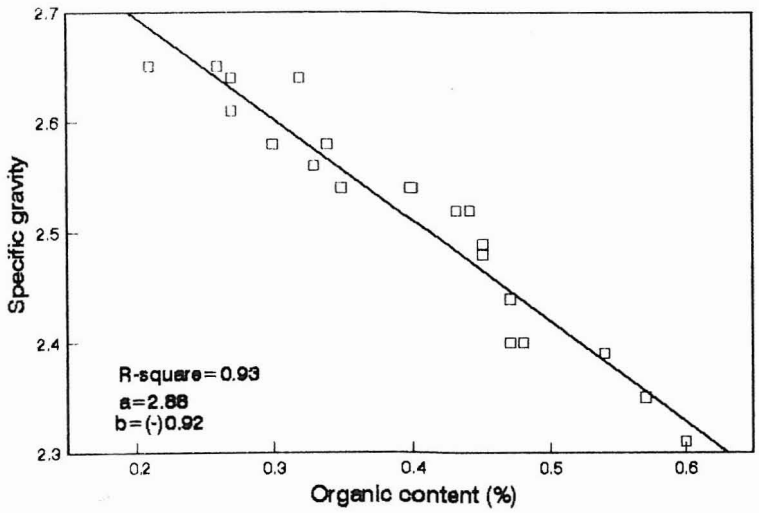

Fig. 9. Specific gravity in relation to organic content

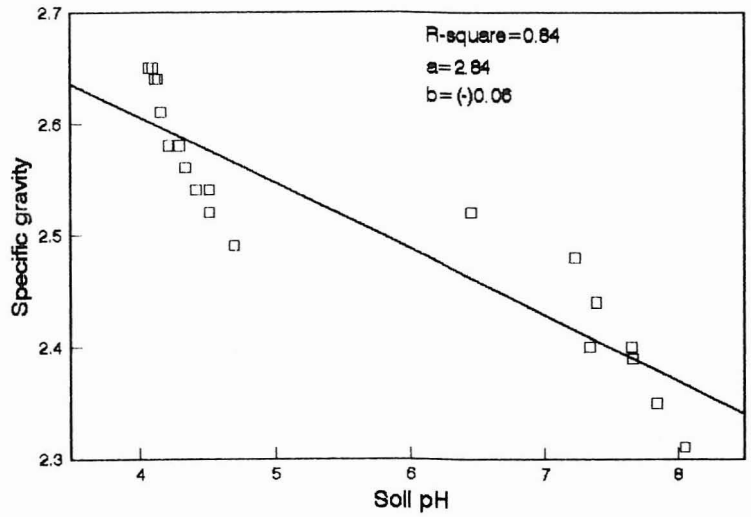

Fig. 10. Specific gravity versus soil pH

Fig. 10 shows the soil specific gravity as a function of soil pH. Linear regression equation for the line is shown in equation 7.

$$Y = 2.84 - 0.06X \quad (7)$$

where Y is specific gravity and X is soil pH. Decreasing soil specific gravity is attributed to increase in soil pH. Soil pH is influenced by the organic content as shown in *Fig. 7*. Increasing the BOD load on the sand-kaolinite mixture led to increase in soil organic content as well as soil pH. Higher soil pH may cause obstruction for particle flocculation (Sridharan *et al.* 1988), whereas at low soil pH, a positive edge negative face flocculation is developed, enhancing flocculation and thus increasing soil specific gravity.

CONCLUSIONS

The study shows that application of organic matter loads to soil changes the basic properties of the soil. Soil specific gravity, index properties, i.e. liquid limits, plastic limit and linear shrinkage limit, and soil organic content and soil pH of four soil columns changed significantly according to increasing BOD load. These changes are due to the increase in soil pH. A high soil pH creates an obstruction to particle flocculation because the higher the pH, the greater the affinity for the hydrogen to go into solution and the greater the effective negative charges of soil particles. Interparticle attraction and repulsion forces of the diffused double layer determine the particle arrangement, which governs the specific gravity and Atterberg limit values.

REFERENCES

ABDUL HAI MAJUMDER, M. 1987. Effects of palm oil mill effluent application on physical and physico-chemical properties of soils. Ph.D thesis, Dept. of Soil Science, Faculty of Agriculture, UPM.

ANON. 1982. Proposed palm oil mill effluent standard for water course discharge. *Planter* 58: 104-112.

CHAN, K.W., I. WATSON and K.C. LIM. 1980. Use of oil palm waste material for increased production. In *Proceedings of Conference on Soil Science and Agricultural Development in Malaysia* ed. E.L. Pushparajah. p. 213-214. Malaysian Society of Soil Science.

FERNANDEZ, F and R.M. QUIGLEY. 1985. Hydraulic conductivity of natural clays permeated with simple liquid hydrocarbons. *Canadian Geotechnical Journal* **22(2):** 669-681.

FOREMAN, D.E. and D.E. DANIEL. 1986. Permeation of compacted clay with organic chemicals. *J. Geotechnical Engineering ASCE* **112(7)**: 205-214.

FRANKLIN, A.G, L.P. OROZEO and R. SEMRAU. 1973. Compaction and strength of slightly organic soils. *J. Soil Mech. and Found. Div. ASCE* **99(SM 7):** 541.

HAMIDON, A.B and H.A. FAISAL. 1989. Organic leachate effects on permeability of compacted kaoline. *Japanese Society of Soil Mechanics and Found. Engin.* **29(2):** 15-23.

LIM, K.H. 1986. Optimising land application of digested palm oil mill effluent. Ph.D. thesis, Faculty of Agriculture, State University of Ghent, Belgium.

MOHD. ALI, B.A. 1986. Effects of palm oil mill effluent, ferrous industry effluent and their mixtures on aggregation and aggregate stability. Project paper, Faculty of Agriculture, UPM.

RAO, S.M, A. SRIDHARAN and S. CHANDRAKARAN. 1989. Influence of drying on the liquid limit behaviour of a marine clay. *Geotechnique* **39(4):** 715-719.

SCHOFIELD, R.K. and R.H. SAMSON. 1954. Flocculation of kaolinite due to attraction of oppositely charged forces. *Discuss. Faraday Soc.* **18:** 135-145.

SHARIFUDDIN, H.A.H. and R.F.P. DYNOODT. 1981. Basic guide to soil and plant analysis. Technical Bulletin, Faculty of Agriculture, UPM.

SIVAPULLAIAH, P.V. and A. SRIDHARAN. 1985. Effects of polluted water on the physico-chemical properties of clayey soils. In *9th Bangkok Geotechnical Symposium and Specialty Session,* Dec. 1985, Thailand, p.179-189.

SREEPADO, R.A. 1982. Physical-chemical properties and engineering behaviour of anion adsorbed clays. Ph.D. thesis, Indian Institute of Science, Bangalore.

SRIDHARAN, A. and R.G. VENKATAPPA. 1975. Mechanism controlling liquid limit of clays. In *Proc. Conf. Soil Mech. Fdn. Engin. Istanbul,* 1, p. 75-84.

SRIDHARAN, A, S.M. RAO and N.S. MURTHY. 1988. Liquid limit of kaolinite soils. *Geotechnique* **38(2):** 181-198.

TOWNSEND, F.C. 1985. Geotechnical characteristics of residual soils. *J. Geotech. Engin. Proc. ASCE* **111:** 77-93.

WASTI, Y. 1987. Liquid and plastic limits as determined from the fall cone and Casagrande methods. *Geotech. Testing J. ASCE* **10(1):** 26-30.

WHITE, W.A. 1949. Atterberg plastic limits of clay minerals. *American Mineral* **34:** 508-512.